Amendments to the Drawing:

In Fig. 1, a reference number has been added to the capacitive load 54 representing the smart material actuator.

In Fig. 2, an arrow pointing to the power source 12 has been added.

In Figs. 3 and 4, the lead line to the bead inductor 52 has been moved to more clearly indicate the inductor 52.

Attachments: Three (3) replacement drawing sheets including one sheet replacing the current sheet incorporating Fig. 1, one sheet replacing the current sheet incorporating Fig. 2 and one sheet replacing the current sheet incorporating Figs. 3 and 4

REMARKS

In the Office Action dated September 1, 2004, the Examiner rejects claims 1-42 under 35 U.S.C. § 112, first paragraph and second paragraph. The Examiner rejects claims 1-28 and 33-42 under 35 U.S.C. § 102(b) and rejects claims 30-32 without providing a basis for doing so. The Examiner objects to claim 29, but indicates that it contains allowable subject matter. Finally, the Examiner provisionally rejects claims 1-42 under the judicially created doctrine of obviousness-type double patenting. With this Amendment, claims 1, 5, 12, 19-23, 27, 34 and 40-42 are amended. Claims 4 and 26 are canceled, and claims 43 and 44 are added. After entry of this amendment, claims 1-3, 5-23 and 25-44 are pending in the application. Reconsideration of the Application as amended is respectfully requested.

With this Amendment, the Applicant is submitting a Substitute Specification. The Substitute Specification filed herewith includes no new subject matter, but has been amended to correct minor typographical and grammatical errors and to revise a reference to a related application. In addition, it has been amended to conform to the changes to the drawing figures. Finally, it has been changed to clarify the operation and connections of the terminals of the comparators in conformance with the language used by those skilled in the art. A redline/strikeout version of the Substitute Specification is also attached that shows the changes that have been made to the original specification as required by Section 608.01(Q) and 714.20(1) of the Manual of Patent Examining Procedure. Entry of the Substitute Specification is respectfully requested.

The Applicant has corrected Figs. 1-4. In Fig. 1, a reference number has been added to the capacitive load 54 representing the smart material actuator and the specification has been amended according to refer to the load 54. In Fig. 2, an arrow pointing to the power source 12 has been added. Finally, in Figs. 3 and 4, the lead line to the bead inductor 52 has been moved to more clearly indicate the inductor 52. The Examiner's approval of the proposed drawing corrections is respectfully requested.

The Examiner rejects claims 1-42 under 35 U.S.C. § 112, first paragraph, for failing to comply with the enablement requirement. Specifically, the Examiner states that neither the specification nor the claims define the term "smart material." Consequently, the Examiner states that the claims contain subject matter that is not described in such a way as to enable one skilled in the art to make and/or use the invention. It is respectfully submitted that the meaning of the term "smart material" is well settled such that neither the specification nor the claims need define the term in order for one skilled in the art to understand it. The term "smart material" refers to a class of materials that includes piezoelectrics, thermoelectrics, pyroelectrics, magnetostrictives, electrostrictives, etc., that share the common characteristic that they provide for direct coupling between electrical and mechanical energy. That is, they respond to an electrical signal with mechanical action and vice versa. This is described in, for example, U.S. Patent No. 6,188,160, which issued on Feb. 13, 2001. The Applicants respectfully submit that claims 1-42 are enabled pursuant to 35 U.S.C. § 112, first paragraph.

The Examiner similarly rejects claims 1-42 under 35 U.S.C. § 112, second paragraph, as being indefinite for failing to particularly point out and distinctly claim the subject matter that the Applicants regard as the invention. The Examiner states that the failure to define the term "smart material" renders the claim indefinite. It is respectfully submitted that the definition of "smart material" is not needed in the claim and that the explanation above makes it clear that claims 1-42 meet the requirements of 35 U.S.C. § 112, second paragraph.

With this Amendment, the Applicant has made certain changes to the claims to more particularly point out and distinctly claim the invention. Claim 1 has been amended to clarify the term a voltage controlled DC to DC converter for operating the smart material actuator in a proportional manner. Specifically, the following features are added: a constant supply voltage supplying the voltage controlled DC to DC converter; and a control signal providing a selectable input voltage wherein an output voltage of the DC to DC converter is applied to the smart material actuator and wherein the output voltage is proportional to the selectable

input voltage. Claim 23 has been similarly amended to incorporate the features of supplying a constant supply voltage to the voltage controlled DC to DC converter and of providing a control signal having a selectable input voltage wherein an output voltage of the DC to DC converter is applied to the smart material actuator and wherein the output voltage is proportional to the selectable input voltage. To conform to these changes, claims 12 and 34 have been amended to correct antecedent basis. Claims 4 and 26 have been canceled without prejudice. As a consequence of canceling these claims, claims 5 and 27 have been amended to correct antecedent basis and to depend from claims 2 and 24, respectively. Finally, in each of claims 19-22 and 40-42, the switch has been amended to describe the switch circuit to correct antecedent basis.

The Applicant gratefully acknowledges the indication of allowable subject matter in claim 29. The Applicant has not amended claim 29 to independent form as claim 19 depends from claims 23 and 24, which are allowable for the reasons set forth hereinafter.

The Examiner rejects claims 1, 15, 23 and 35 under 35 U.S.C. § 102(b) as being anticipated by Hoffman et al. (US 6,137,208). In support of this rejection, the Examiner states that Hoffman et al. includes a piezoelectric actuator (P), a control circuit (ST), switches (X1-X4), a coil (L) and diodes (D). It is respectfully submitted that Hoffman et al. teaches a device and method for driving a capacitive actuator Pn that first pre-charges a capacitor C from an undefined voltage source V, upon application of an enable signal (st), switches the capacitor C to the actuator Pn through an inductor L, allows the actuator Pn to charge until its voltage (from VM) compares to the desired value and stays in the charged state until the enable signal (st) is removed. Then, the actuator Pn is completely discharged into the pre-charge cap C, inductor L, and diode D2.n. It is respectfully submitted that Hoffman et al. fails to teach the feature of claim 1 and of claim 23 of a voltage controlled DC to DC converter operating the smart material actuator in a proportional manner. Hoffman et al. uses an oscillating LC circuit to charge a capacitive actuator to a predetermined setpoint and then discharges the actuator to ground. The oscillating LC circuit cannot

be considered a voltage controlled DC to DC converter, and it cannot be said to operate the capacitive actuator in a proportional manner since the method always discharges to ground. Moreover, Hoffman et al. does not teach or suggest a control signal providing a selectable input voltage wherein an output voltage of the DC to DC converter is applied to the smart material actuator and wherein the output voltage is proportional to the selectable input voltage. Thus, claims 1 and 23 and their dependent claims are allowable over Hoffman et al.

It is also submitted that Hoffman et al. fails to teach or suggest the feature of claim 15 of a switch circuit for actively discharging the smart material actuator in response to removal of the connection to the power source and of claim 35 of actively discharging the smart material actuator in response to removal of the connection to the power source with a switch circuit. As can be seen from Fig. 2 and from the description of Hoffman et al. above, discharge occurs in response to st=0 in step 60. This switches X3 and X4 such that current flows from the actuator Pn to discharge it. In Hoffman et al., when X1 stops current from flowing from the voltage source V to the capacitor C, active discharge of the actuator Pn does not occur. Thus, active discharge does not occur in response to removal of the connection to a power source. Hoffman et al. fails to address the important issue of discharging the actuator upon loss of the power source versus loss of the control signal. This is important for smart material actuators because, unlike a solenoid, such actuators tend to hold their last position due to their capacitive nature. In most practical applications, such as a valve, one would want that valve to close upon loss of supply power. For the foregoing reasons, claims 15 and 35 and their dependent claims are allowable over Hoffman et al.

The Examiner rejects claims 1, 11, 12, 15-23 and 33-42 under 35 U.S.C. § 102(b) as being anticipated by Schrod (WO 01/22502A). The Examiner states that Schrod discloses a method and circuit for driving a capacitive actuator (P1) comprising a voltage-controlled DC/DC converter for operating the actuator and a switch circuit for charging discharging the actuator in response to connection/removal to the power source. It is respectfully submitted that Schrod discloses a DC/DC

converter V, which receives a vehicle power supply system voltage. The capacitor C1 starts charged to the output voltage of the DC/DC converter V. The energy stored in the capacitor C1 is supplied to the actuator Pn via switching of the primary of the transformer Tr using pulse-width modulation. As shown in Fig. 2, those pulses occur over a period of time. Schrod mentions monitoring the actuator voltage for comparison with threshold values, but there is no indication of how that comparison is performed and what is done with the result of the comparison.

With respect to claim 1 and its dependent claims, including claims 11 and 12, it is respectfully submitted that Schrod lacks any teaching of the combination of a voltage controlled DC to DC converter for operating the smart material actuator in a proportional manner; a constant supply voltage supplying the voltage controlled DC to DC converter; and a control signal providing a selectable input voltage wherein an output voltage of the DC to DC converter is applied to the smart material actuator and wherein the output voltage is proportional to the selectable input voltage. Schrod also fails to teach or suggest the similar features in claim 23 and its dependent claims, including claims 33 and 34.

In addition to the foregoing, Schrod fails to teach or suggest the feature of claim 11 and claim 33 where a smart material drive circuit actively charges and discharges the smart material actuator in response to connecting and disconnecting a power source, respectively. To discharge the voltage of the smart material actuator, Scrod switches the secondary of a transformer using pulse modulation signals. Like Hoffman et al., Schrod fails to address the issue of discharging the actuator upon loss of the power source.

Similarly, Schrod fails to teach or suggest the feature of claim 15 and its dependent claims 16-22 of a switch circuit for actively discharging the smart material actuator in response to removal of the connection to the power source and the feature of claim 35 and its dependent claims 36-42 of actively discharging the smart material actuator in response to removal of the connection to the power source with a switch circuit. Schrod fails to address the issue of discharging the actuator upon loss of the power source; the discharge of the actuator is the result of pulsed

switching on the secondary of the transformer. Thus, claims 15 and 35 and their dependent claims are allowable over the prior art of record.

In addition to the foregoing, it is respectfully submitted that the Examiner fails to point to, and the Applicant is unable to find, any teaching or suggestion in Schrod of the features of claims 19 and 21 wherein the switch circuit described in claim 15 further comprises a voltage comparator and FET transistor. Thus, these claims are allowable over the prior art of record for this reason also.

The Examiner rejects claims 1-14, 15-28 and 33-42 under 35 U.S.C. § 102(b) as being anticipated by Tomono (US 4,625,137). The Examiner states that Tomono discloses an apparatus comprising a piezoelectric actuator 1, a controllable power source 2, 4, 5 and Ec, switching circuitry 3, a DC/DC converter (col. 5, ll. 41-45) having a transformer TR including primary and secondary windings 11, 12, 14 and a diode ZD1. With respect to claim 14, the Examiner acknowledges that Tomono does not disclose the transformer as having an LTCC design, but states that the limitation has not been given patentable weight. It is respectfully submitted that Tomono discloses a bimorph Piezoelectric actuator including a drive circuit 2 using a self-oscillating DC/DC converter providing a constant voltage source 4 and a polarity reversing switch 3 that applies power in a on/off AC fashion (reversing polarity). Thus, it is submitted that Tomono only discloses controlling a capacitive load in an on/off fashion using a constant voltage source. It does not teach or suggest the feature of claim 1 and its dependent claims 2-14 and of claim 23 and its dependent claims 24-28, 33 and 34 of a voltage controlled DC to DC converter operating the smart material actuator in a proportional manner. In addition, it fails to teach or suggest the feature of claim 1 and its dependent claims of a constant supply voltage supplying the voltage controlled DC to DC converter and a control signal providing a selectable input voltage wherein an output voltage of the DC to DC converter is applied to the smart material actuator and wherein the output voltage is proportional to the selectable input voltage. Tomono also fails to teach or suggest the similar features in claim 23 and its dependent claims.

In addition to the foregoing, Tomono fails to teach or suggest the feature of claim 11 and claim 33 where a smart material drive circuit actively charges and discharges the smart material actuator in response to connecting and disconnecting a power source, respectively. Tomono provides a constant voltage source (circuit 4) for applying a constant voltage to the drive input circuit (circuit 2). (See Abstract and Fig. 1). The Examiner has not pointed to anything in Tomono, and the Applicant is unable to find in Tomono, that teaches or suggest the features of these claims. Thus, they are allowable over the prior art of record.

Similarly, Tomono fails to teach or suggest the feature of claim 15 and its dependent claims 16-22 of a switch circuit for actively discharging the smart material actuator in response to removal of the connection to the power source and the feature of claim 35 and its dependent claims 36-42 of actively discharging the smart material actuator in response to removal of the connection to the power source with a switch circuit. Like Hoffman et al. and Schrod, Tomono does not address the issue of discharging the actuator upon loss of the power source. Thus, claims 15 and 35 and their dependent claims are allowable over the prior art of record.

The Applicant has also reviewed Tomono and is unable to find any teaching or suggestion in Tomono of the features of claims 19 and 21 wherein the switch circuit described in claim 15 further comprises a voltage comparator and FET transistor. The Examiner has also failed to point to these features in the reference. It is respectfully submitted that the invention as defined by claims 19 and 21 and their dependent claims is patentable over the prior art of record.

The Examiner rejects claim 30-32 without identifying a basis for the rejections. Based upon the features recited therein, the Applicant assumes that the Examiner is rejecting these claims on the same basis as claims 8-10, namely, that Tomono teaches all the features therein. It is respectfully submitted that these claims are allowable for the reasons stated above with respect to claims 8-10 and based upon their dependence from claim 23.

The Examiner provisionally rejects claims 1-42 under the judicially created doctrine of obviousness-type double patenting as being unpatentable over

claims 1-30 of copending Application Serial No. 10/621,797. Enclosed herewith is a Terminal Disclaimer, which obviates the Examiner's double patenting rejection.

With this Amendment, new claims 43 and 44 have been added to include unique features disclosed in the Application as originally filed, but which were not previously claimed in their present manner. Examination and allowance of claims 43 and 44 is respectfully requested.

It is respectfully submitted that this Amendment traverses and overcomes all of the Examiner's objections and rejections to the application as originally filed. It is further submitted that this Amendment has antecedent basis in the application as originally filed, including the specification, claims and drawings, and that this Amendment does not add any new subject matter to the application. Reconsideration of the application as amended is requested. It is respectfully submitted that this Amendment places the application in suitable condition for allowance; notice of which is requested.

If the Examiner feels that prosecution of the present application can be expedited by way of an Examiner's amendment, the Examiner is invited to contact the Applicant's attorney at the telephone number listed below.

Respectfully submitted,

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Dated: December 22, 2004
TDH/MLK

Our Reference: VTE-141-B PATENT

APPARATUS AND METHOD FOR CHARGING AND DISCHARGING A CAPACITOR TO A PREDETERMINED SETPOINT

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of U.S. Provisional Application No. 60/408,468 filed on September 5, 2002 which is incorporated by reference herein. This application is related to ~~a continuation of~~ U.S. ~~Provisional~~Patent Application No. ~~60/408~~10/621,~~277~~797 filed on ~~September 5~~July 17, 200~~2~~3 for an Apparatus and Method for Charging and Discharging a Capacitor.

FIELD OF THE INVENTION

[0002] The present invention relates to electronic methods and circuits for controlling proportional general purpose, smart material-based actuators.

BACKGROUND OF THE INVENTION

[0003] Actuator technologies are being developed for a wide range of applications. One example includes a mechanically-leveraged smart material actuator that changes shape in response to electrical stimulus. This change in shape is proportional to the input voltage. Since this shape change can be effectuated predominantly along a single axis, such actuators can be used to perform work on associated mechanical systems including a lever in combination with some main support structure. Changes in axial displacement are magnified by the lever to create an actuator with a useful amount of force and displacement. Such force and displacement is useful for general-purpose industrial valves, clamps, beverage dispensers, compressors or pumps, brakes, door locks, electric relays, circuit breakers, and other applications actuated by means including solenoids, motors or motors combined with various transmission means. Smart materials, however, and piezoelectric materials specifically, can require hundreds of volts to actuate and cause displacement. This type of voltage may not be readily available and may have to be derived from a lower voltage as one would find with a battery.

[0004] Another characteristic of piezoelectric materials is that the materials are capacitive in nature. Moreover, a single actuator is often controlled using three separate signals: a control signal, a main supply and a ground.

SUMMARY OF THE INVENTION

[0005] An apparatus for charging and discharging a capacitor to predetermined setpoints includes a smart material actuator and a voltage controlled direct current (DC) to DC converter for operating the smart material actuator in a proportional manner. The voltage controlled DC to DC converter can further include a self-oscillating drive circuit connected to a primary coil of a transformer with push-pull drive signals 180 degrees out of phase. The voltage controlled DC to DC converter can also include an auxiliary coil on the transformer. An attached diode rectifier to generate a DC voltage from an AC signal of the secondary coil on the transformer can also be included with the DC to DC converter as well as a voltage feedback network for voltage regulation.

[0006] The voltage controlled DC to DC converter can further include control circuitry for stopping and starting the self-oscillating mechanism and can also feature a diode on an input stage for reverse polarity protection. Moreover, the control circuitry can further include a bead inductor and bypass capacitor for suppression of radiated EMI into the power source of the system.

[0007] Another feature of the invention includes a smart material drive circuit for actively charging and discharging the smart material actuator in response to connecting and disconnecting a power source, respectively. The drive circuit for actively controlling at least one of charging and discharging the smart material actuator can be responsive to a control signal.

[0008] Yet another embodiment of the invention for charging and discharging a capacitor to predetermined setpoints includes a smart material actuator, a power source connectible to the smart material actuator, and a switch circuit for actively discharging the smart material actuator in response to removal of the connection to the power source. The switch circuit for actively charging the smart material actuator can further be responsive to connecting the power source or a control signal input. The switch circuit can actively control at least one of charging and discharging the smart material actuator in response to a control signal and can further include a voltage comparator and field effect transistor (FET) to control the DC to DC converter. The switch can, according to the invention, have three

operational modes, charge load, hold load and discharge load. Hence, the method for charging and discharging a capacitor to predetermined setpoints according to the present invention includes the steps of providing a smart material actuator and operating the smart material actuator in a proportional manner with a voltage controlled DC to DC converter. An alternative method for charging and discharging a capacitor to predetermined setpoints according to the invention includes the steps of providing a smart material actuator, connecting a power source to the smart material actuator, and actively discharging the smart material actuator in response to removal of the connection to the power source with a switch circuit.

[0009] With the use of electronic design and simulation software and electronic prototyping of the circuit, details for using a minimum number of components while maintaining a cost-effective, and low power solution are realized. This electronic subsystem, when coupled to a mechanically-leveraged smart material actuator, creates a commercially viable proportional actuator solution for general purposes and industrial applications.

[0010] Other applications of the present invention will become apparent to those skilled in the art when the following description of the best mode contemplated for practicing the invention is read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The description herein makes reference to the accompanying drawings wherein like reference numerals refer to like parts throughout the several views, and wherein:

[0012] Fig. 1 is an electronic schematic of a voltage controlled DC to DC converter with active regulation to which the present invention is applied;

[0013] Fig. 2 is an electronic schematic of a DC to DC converter of the present invention;

[0014] Fig. 3 is an electronic schematic of the electronic switch of the present invention illustrating current flow when the switch is closed;

[0015] Fig. 4 is an electronic schematic of the electronic switch of the present invention illustrating current flow when the switch is open; and

[0016] Fig. 5 is an electronic schematic of the control circuit of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[0017] Figure 1 shows an electronic schematic of a system 10 for controlling a proportional mechanically leveraged smart material actuator (~~not~~ shown as capacitor 54) including a specialized power source 12 coupled to switching circuitry 44 and control circuitry 64.

[0018] According to the preferred embodiment, the ~~specialized power source~~system 10 of Figure 1 is a DC to DC converter, switching circuit, and control circuit operative either to supply a variable stimulating voltage or to actively discharge the actuator. As best shown in Figure 2, the DC to DC converter 12 ~~(12 is missing from Fig. 2)~~ includes a supply voltage 14 connected to a bead inductor 16 ~~which feeds~~in series with a reverse protection diode 18. Bead inductor 16 acts as a filter to remove noise generated by the collector of negative positive negative (NPN) transistor 20 connected to the supply voltage 14. NPN transistor 20 and NPN transistor 22 form a push-pull driver for transformer 24. Resistors 26, 28, 30~~,~~ and 32 form ~~a~~ resistive voltage dividers and set the basic bias points for NPN transistors 20 and 22.

[0019] Transformer 24 is wound not only with a primary coil 24a and a secondary coil 24b, but also with an auxiliary coil 24c. Auxiliary winding 24c~~, transformer 24,~~ resistors 34, 36, 28, and capacitors 38, 40 form feedback means to cause oscillation on the base of NPN transistors 20, 22. Oscillation is 180 degrees out of phase between the two NPN transistors 20, 22, forming a self-oscillating push-pull transformer driver. The secondary coil 24b of transformer 24 is connected to a rectifier in the form diode 42. It should be noted that when the base of transistor 22 is grounded, the self-oscillating mechanism is stopped. When the ground is removed, the self-oscillating mechanism is restarted. As shown in Figure 1, switch circuitry 44, when commanded, is capable of actively controlling the voltage to the capactitive load.

[0020] Control circuitry 64 monitors the control voltage and output voltage and makes the decision to turn on the DC to DC converter, or turn on the discharge

switch, or hold the current voltage level at the capacitive load. Included in the system is means for forcing the load to ground should the supply voltage be removed.

[0021] Referring now to Figure 3, switching circuitry 44 is depicted isolated from the schematic of Figure 1 to better illustrate the operative features of the switching circuitry 44 when it is closed. When switch 48 is closed, current flows from a power source 50 through switch 48 and through bead inductor 52, charging the capacitive load 54. Also, current flows into resistive voltage divider~~ network~~ 56 driving the NPN transistor 58 on, which turns NPN Darlington pair 60 off. The rate of charge is determined by the impedance of the power source 50 and the capacitance of the load 54. Resistor 62 and NPN transistor 58 serve as a level translator between the switched power and control signal, so the switched power and control signal do not have to have the same voltage levels.

[0022] Referring now to Figure 4, the current flow in switching circuitry 44 is shown when switch 48 is open. When switch 48 is open, no current flows from the power source 50. Also, current flows into resistive voltage divider~~ network~~ 56 through switch 48 to ground, driving the NPN transistor 58 off~~, which~~. This turns NPN Darlington pair 60 on, causing current flow through resistor 46 and discharging capacitive load 54. The rate of discharge is determined by the value of resistor 46 and capacitive load 54. Resistor 62 and NPN transistor 58 serve as a level translator between the switched power and control signal so the switched power and control signal do not have to have the same voltage levels.

[0023] Referring now to Figure 5, the control circuit 64 of Figure 1 is shown isolated to better illustrate the operative features of the circuit 64. Analog control voltage flows through resistor 66 and is clamped by Zener diode 68 at a preset voltage so as not to damage the input of operational amplifier 70. Further, resistor 66 is part of resistive ~~dividing~~voltage divider network 72. The network 72 ~~derives~~provides two voltages; one voltage is the reference to shut the DC to DC converter 12 down, the other, a reference to actively discharge the capacitive load. Operational amplifier 70 is used in a voltage comparator mode that is associated with the DC to DC converter 12 shutdown mode. Operational amplifier 74 is used in a voltage comparator mode and is associated with the active discharge mode. Resistors

76, 78, 80 form a second resistive voltage divider network. This network monitors the capacitive load voltage and derives the voltages that operational amplifiers 70, 74 compare to the reference voltages derived from resistors 66, 72. When the voltage at the ~~plus~~non-inverting terminal of operational amplifier 70 is greater than the ~~minus~~voltage at the inverting terminal, the output of the amplifier goes to the ~~plus~~positive saturation state, turning FET transistor 82 on and causing the DC to DC converter to stop.

[0024] When the voltage at the ~~minus~~inverting terminal of operational amplifier 70 is greater than that at the ~~plus~~non-inverting terminal, the output of the amplifier goes to the ~~minus~~negative saturation state, turning FET transistor 82 off and causing the DC to DC converter to run. When the voltage at the ~~plus~~non-inverting terminal of operational amplifier 74 is greater than that at the ~~minus~~inverting terminal the output of the amplifier goes to the ~~plus~~positive saturation state, turning FET transistor 84 on and causing the active discharge of capacitive load. When the voltage at the ~~minus~~inverting terminal of operational amplifier 74 is greater than the ~~plus~~voltage at the non-inverting terminal, the output of the amplifier goes to the ~~minus~~negative saturation state, turning FET transistor 84 off. In this system there are three distinct states, (1) DC to DC converter on and capacitive load discharge switch open, (2) DC to DC converter off and capacitive load discharge switch open, and (3) DC to DC converter off and capacitive load discharge switch ~~on~~closed.

[0025] In the embodiment illustrated in Figures 1, 2, 3, 4, and 5,the components have been chosen for their current carrying ability, voltage rating, and type. Other suitable components can include FET small signal, and power transistors, wire wound, thin film, and carbon comp resistors, ceramic, tantalum, and film capacitors, or any combination of suitable components commonly used for high volume production. Although these materials given as examples provide excellent performance, depending on the requirements of an application, use of other combinations of components can be appropriate. Likewise, the embodiment illustrates components that are commercially available.

[0026] While the invention has been described in conjunction with what is presently considered to be the most practical and preferred embodiment, it is to be

understood that the invention is not to be limited to the disclosed embodiment but, on the contrary, it is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims, which scope is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures as permitted under law.